LIMITED CIRCULATION

This paper is not an official document; it is for information only and must not be quoted in any printed publication.

AGRICULTURAL MEMORANDUM NO 1001

The Variation of rainfall with height in Wales

by C P Roe

1. Introduction

In Wales the annual average rainfall varies from under 700 mm in the Vale of Clwyd and in the Queensferry area (NE Wales), to over 4000 mm on the highest peaks of Snowdonia. It is well known that there are close links between altitude and rainfall but, as Fig 1 demonstrates, the relationship is not as simple as it might first appear. Table 1 shows the scatter of rainfall for 100 m increments taken from a sample of over 400 raingauges.

Table 1

Rainfall - variation with height

HEIGHT ASL (m)	RANGE (mm)
100	640 - 2020
100 - 200	730 - 2240
200 - 300	830 - 2430
300 - 400	920 - 2790
400 - 500	1070 - 2540
500 - 600	1400 - 2680

Many workers have endeavoured to relate rainfall to height (and other parameters) and some of their results are included in the next section. The main shortcoming of their work, as far as Wales is concerned, is that it is either too general or too specific to be applicable for the whole of Wales. The results obtained in this study provide a useful, and simple, approach to mapping rainfall averages throughout Wales from height alone.

2. Previous work

2.1 Using data from over 6500 stations, Bleasdale and Chan (1972) established the following relationship between annual average rainfall (AAR) and altitude in Britain:

$$R = 714 + 2.42\,H \qquad (R = \text{AAR in mm, } H = \text{height in m})$$

Considering the anomalies from this regression line (Fig 1) shows anomalies between -800 and +1200 mm occurring in North and South Wales.

2.2 Barrowcliffe (1983) adopted a more vigorous approach by dividing the country up into regions (based partly on intuition and partly on hydrological areas) and obtained a linear regression for each region. He obtained, for Wales, the expression:

$$R = 900 + 2.6\,H \quad (R = \text{AAR in mm, } H = \text{height in m})$$

This is plotted in Fig 1 and it can be seen that large anomalies still remain, ranging between -1100 and +1000 mm.

2.3 Savidge (1966) attempted to relate rainfall and height in Wales by looking at the 35-year means (1916-50) obtained at 404 raingauge sites throughout Wales and a small area of England. He selected a unit area of 5 x 5 km, based on the National Grid, to examine regional variation; his results are summarised in Table 2.

Table 2

Rainfall statistics for the Welsh 5 km^2

	5 km^2	Correlation coefficient r	Increase in rainfall (mm) for every 100 m
1.	Anglesey, Lleyn	0.61	217
2.	N Caerns, W Denbs	0.75	400
3.	Flint	0.85	72
4.	S Caerns, Meirioneth	0.37	133
5.	Montgomery	0.55	92
6.	Cardigan	0.87	192
7.	Radnor	0.85	183
8.	Pembroke	0.51	167
9.	Brecon	0.81	192
10.	Monmouth	0.87	242
11.	Glamorgan	0.76	408
1-11.	All Wales	0.63	241

There was generally a reasonably high correlation between rainfall and altitude except in South Snowdonia (area 4) where r was not significant at the 5% level. This, says the author, is because of "the nature of the area with its numerous mountain peaks and deeply intersected valleys".

2.4 Newson (1976) looked at the variation of rainfall with height at Plynlimon in mid-Wales over the three years october 1971 to September 1974. The expression

$$R = 1530 + 1.71\,H$$

was obtained with a correlation coefficient r = 0.80. This allowed annual rainfall on the catchment to be estimated to within $\pm$ 240 mm (twice the standard error) with 95% probability.

Several other short term studies (eg Rodda, 1962) have attempted to establish linear relationships between rainfall, height and other parameters eg exposure and aspect but the results have been inconsistent from year to year because of the dominating influence of specific weather patterns. By taking long-term averages these difficulties are reduced and this is the approach used in this study.

3. Results

The 1941-70 AAR and height for approximately 400 gauges in Wales, and within close proximity to the border, are shown in Fig 1. Several distinct populations within the overall network seem to be apparent. Arbitrarily three were adapted and designated

Area 1, Area 2 and Area 3. Gauges from each area were plotted on a map to determine their distribution; maps for North and South Wales are shown in Figs 2a and 2b respectively.

Each area demonstrates a remarkable degree of continuity suggesting that there is in fact three distinct distributions. Area 1 receives less rainfall than one would expect for a given altitude, no doubt due to a 'rain shadow' effect in the lee of mountains further West. Area 3 represents those areas exposed to westerly and south westerly winds where rainfall is higher than expected for a given altitude. Area 2, covering the largest area, is apparently neither over exposed or under exposed.

A regression and correlation analysis was performed on rainfall and height data for each area individually. A linear expression of the form $R = a + b H$ was obtained and the results are shown in Table 3; the results are presented graphically in Figs 3a, 3b and 3c.

Table 3

Regression analysis for Wales

Area	No of gauges	Coefficients a	Coefficients b (mm m^{-1})	Correlation r	Standard error of estimate (mm)	Range of Residuals (mm)	Significance level %
1	139	696.90	1.34	0.83	115.02	-273 to 496	0.1
2	196	938.30	2.58	0.88	197.63	-620 to 695	0.1
3	76	1191.71	4.87	0.9	226.23	-272 to +1145	0.1

4. Discussion

Figures 1 and 2a/b illustrate that Wales can satisfactorily be divided into three well defined populations - those with high, medium and low rainfall gradients with altitude. The isolines defining each area, while displaying a fairly simple pattern, have been drawn subjectively and with an eye to aspect and topography, two important features associated with the rainfall distribution.

There were very few inhomogeneities in the well ordered pattern; only 9 occurred out of the 400 gauges studied and these are shown by a dashed circle around the gauges concerned in Figures 2a and 2b. In North Wales there is a definite progression from a high gradient of rainfall with altitude (GRA) in the high ground in the West to a comparatively low GRA in the East. An anomaly occurs in the Aberystwyth area of mid-Wales where the GRA is much lower than that of surrounding areas to the North and East. One might intuitively extend this area South Westwards down the coast to beyond Aberporth (which also has a low GRA) where the topographic influence is likely to be less marked than further North.

In South Wales area 2 bifurcates from a narrow strip in the North into a much larger 'forked tongue' occupying South West and South East areas of Wales. Low GRA areas are still found in Eastern parts associated with rain shadows in the lee of the high ground of the Black Mountains and Brecon Beacons. High GRA areas are restricted to the disected uplands near the South coast.

An interesting isolated area of medium GRA lies along the Worms Head peninsula and inland of Swansea. This could possibly be drawn to show continuity, through gauge 498480, with the main tongue of area 2 but the upland topography between gauges 498721 and 496428 suggests the pattern shown. Area 3 pushes North Eastwards to the West of this area and may well be associated with the funnelling of South Westerly winds between St Govans Head and Worms Head and also between the high ground of the Prescellies and Black Mountains.

The results indicate an annual average GRA of 134,258 and 487 mm per 100 m for areas 1, 2 and 3 respectively and so encompass certain of the gradients found by other workers (see previous work section).

The difficulty in applying the regression equations arises when a site lies near the border of two regions for this is where the largest errors occur. One could overcome this difficulty by introducing more areas but this would detract somewhat from the simplicity of the scheme. An easier solution would be to mean the regression coefficients of the two areas concerned to obtain a more appropriate equation.

Nevertheless, the anomalies incurred by using this method are substantially less than those obtained by using Bleasdale and Chan's and also Barrowcliffe's formulae.

Ultimately, greater accuracy will only be achieved by introducing other microscale or local factors such as aspect and exposure into the equations. However, the improved accuracy so obtained must be traded off against the greater effort involved in estimating point rainfall. In most cases I suspect the accuracy of the simple regressions presented here will suffice.

5. Acknowledgements

The directive comments of Dr J Starr, Regional Meteorological Officer for Wales are gratefully acknowledged. Thanks also to Mr R Finch, Agronomy Department, Trawsgoed for assistance with the statistical analysis.

6. References

Barrowcliffe, R (1983) "The relationship between rainfall and height". Unpublished agricultural memorandum no 976.

Bleasdale, A and Chan, Y K (1972) "Orographic influences on the distribution of precipitation in mountainous areas". Vol II (beilo Symposium, Norway 31 July to 5 August 1972).

Newson, A J (1976) "Some aspects of the rainfall of Plynlimon, mid-Wales". National Environment Research Council Institute of Hydrology Rep 34.

Rodda, J C (1962) "An objective method for the assessment of aerial rainfall amounts". Weather Vol 17, 54-9.

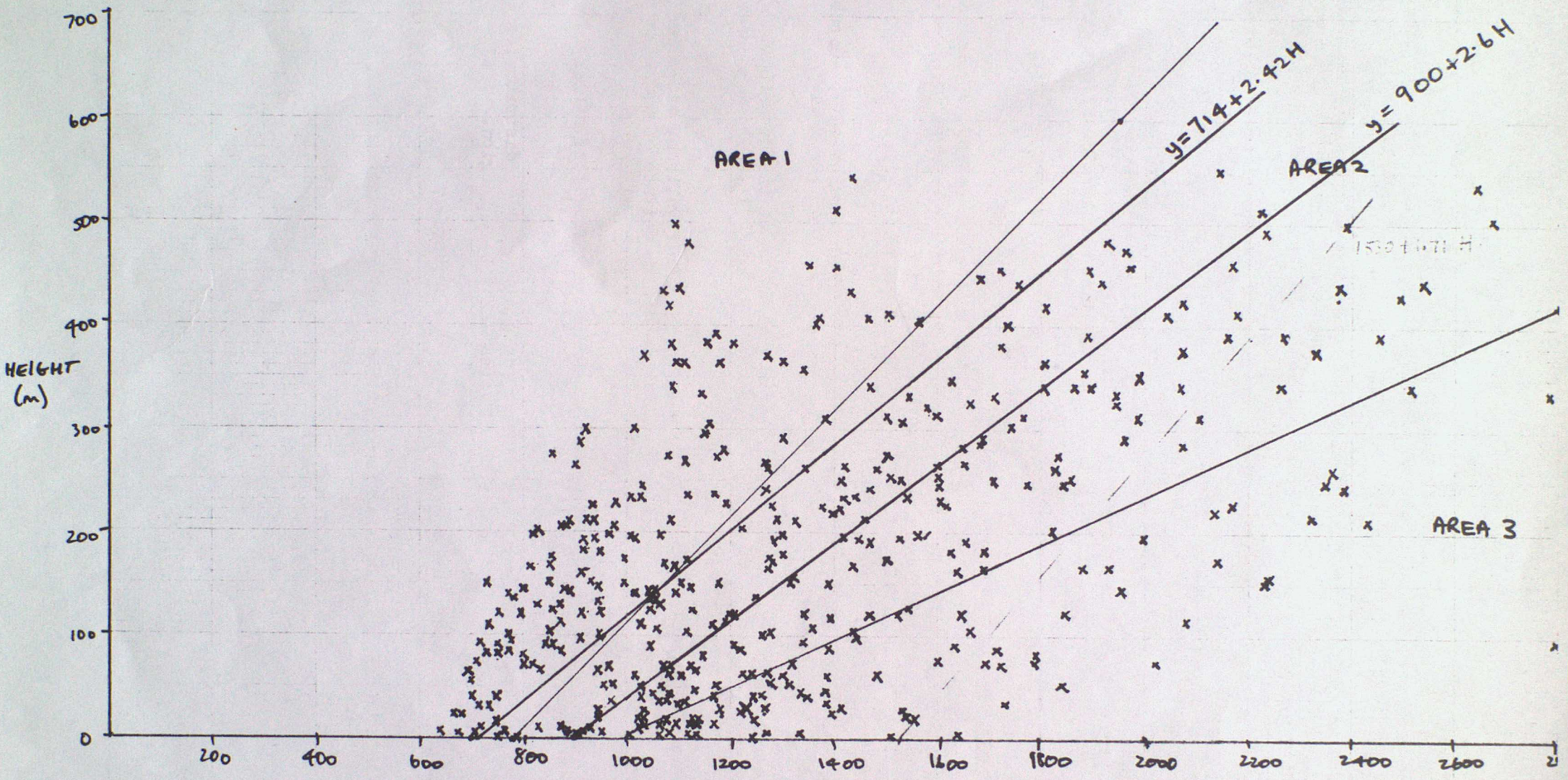
Savidge, J P (1966) "Rainfall as a factor determining plant distribution in Wales". Bot Soc of the British Isles Welsh Region. Bull No 9.

Any comments on this paper should be directed to the author:

C P Roe
Regional Agricultural Meteorology Department
WOAD
Trawsgoed
Aberystwyth
Dyfed SY23 4HT

Fig. 1

VARIATION OF RAINFALL WITH HEIGHT IN WALES



Average Annual Rainfall (mm)

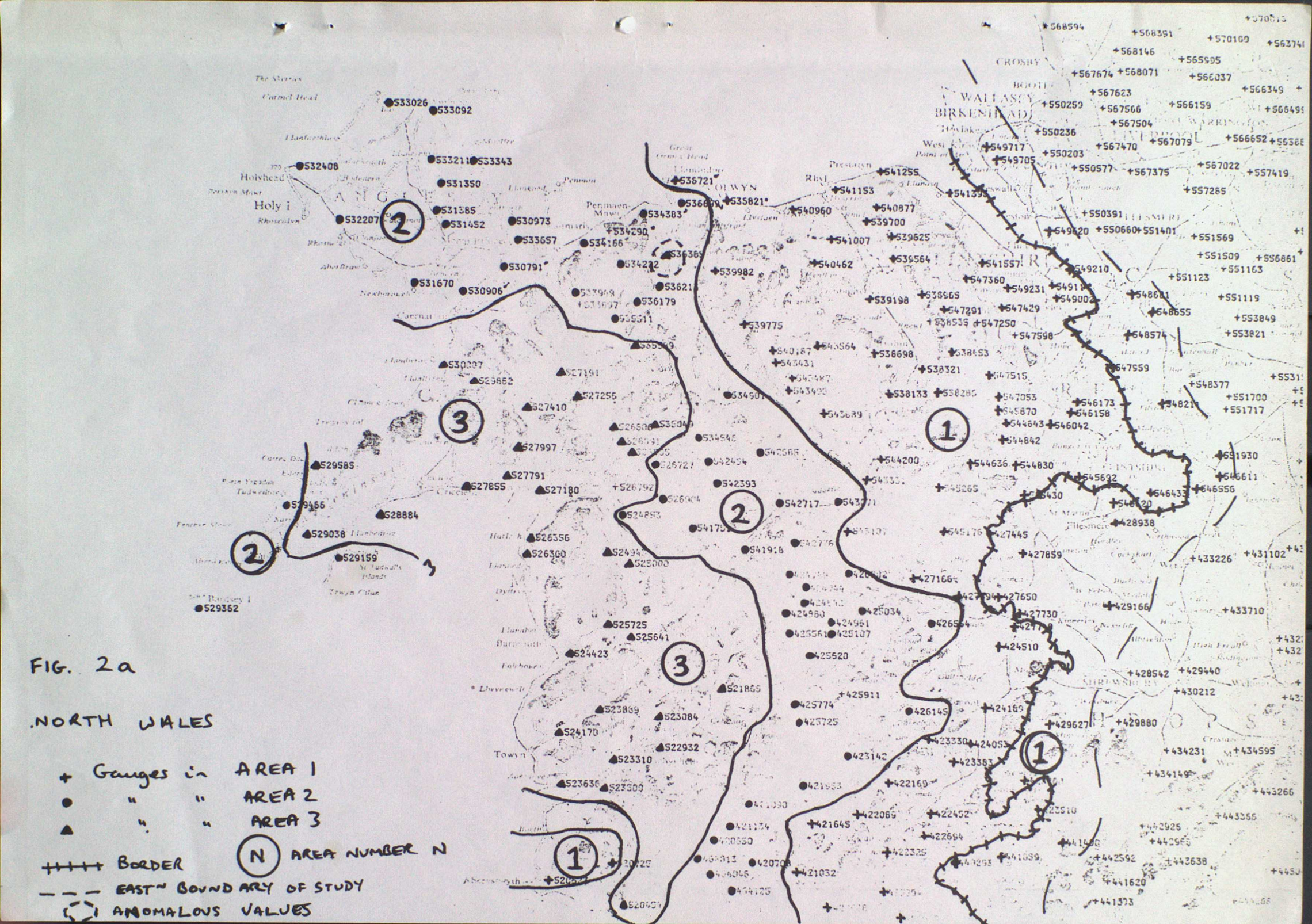


FIG. 2a

.NORTH WALES

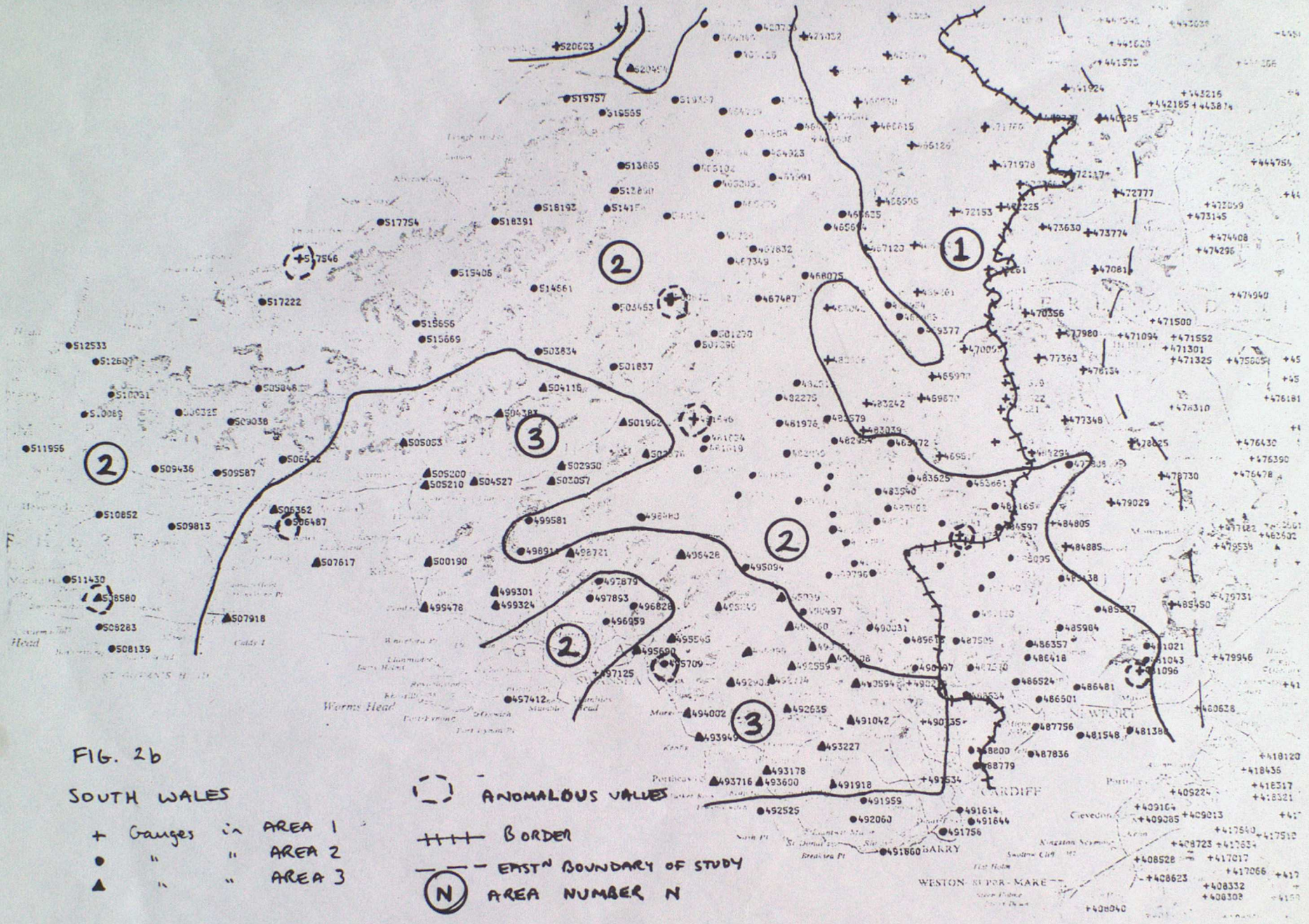


FIG. 2b

SOUTH WALES

+ Gauges in AREA 1
● " " AREA 2
▲ " " AREA 3

ANOMALOUS VALUES

BORDER

EAST^{N} BOUNDARY OF STUDY

(N) AREA NUMBER N

Fig. 3a.

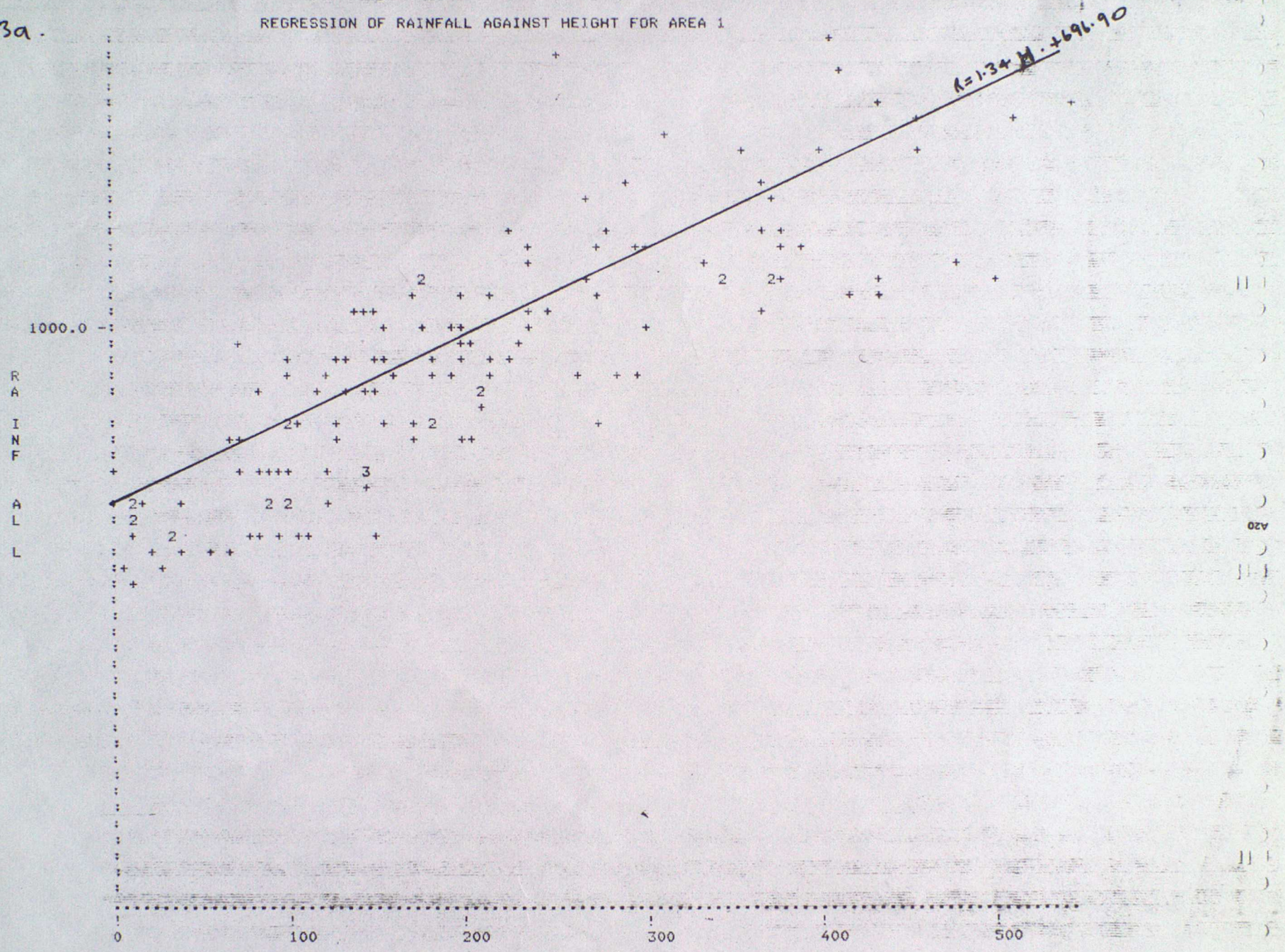

REGRESSION OF RAINFALL AGAINST HEIGHT FOR AREA 1
R
A
I
N
F
A
L
L
1000.0
0
100
200
300
400
500
A20

Fig 3b

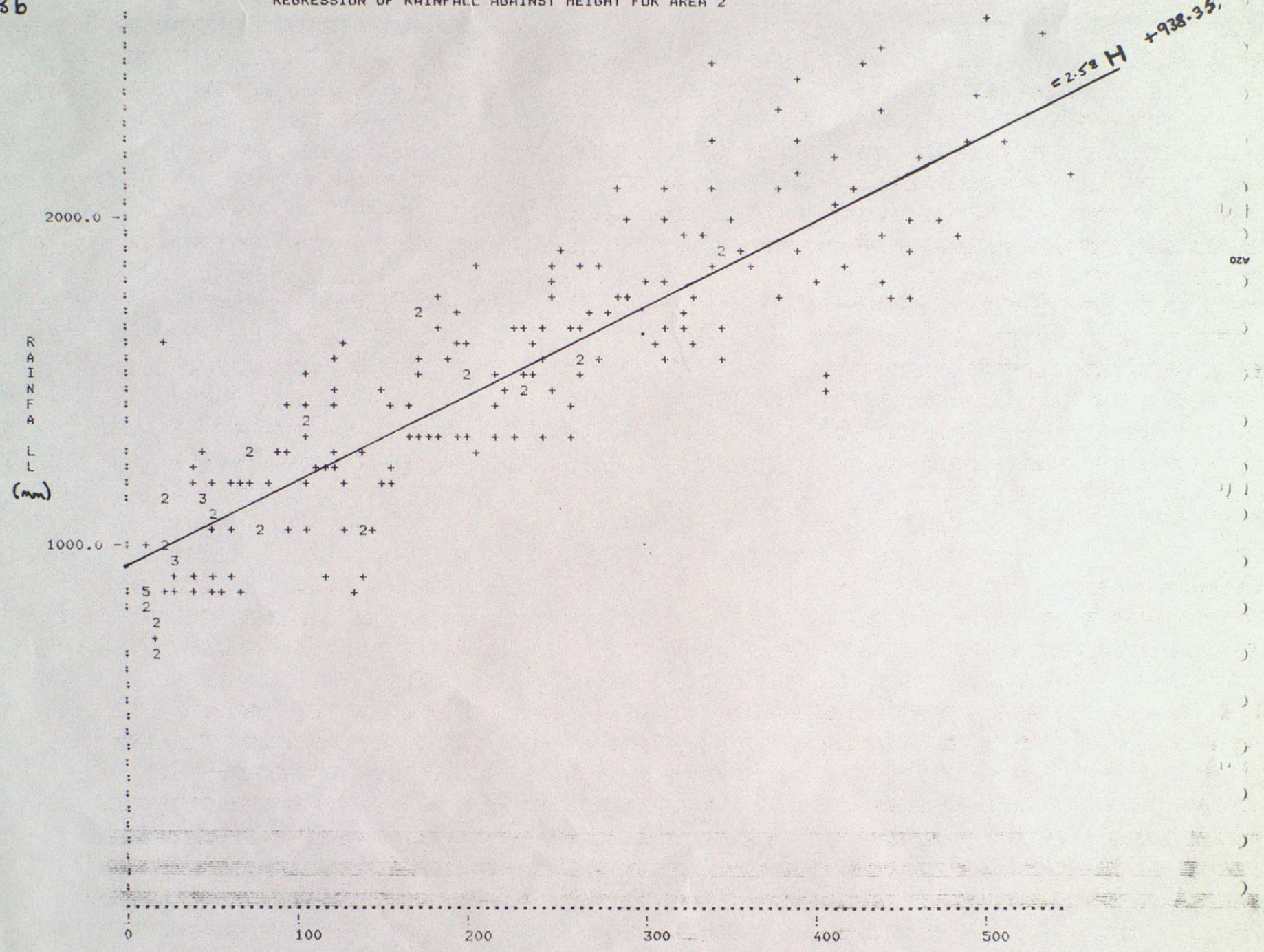
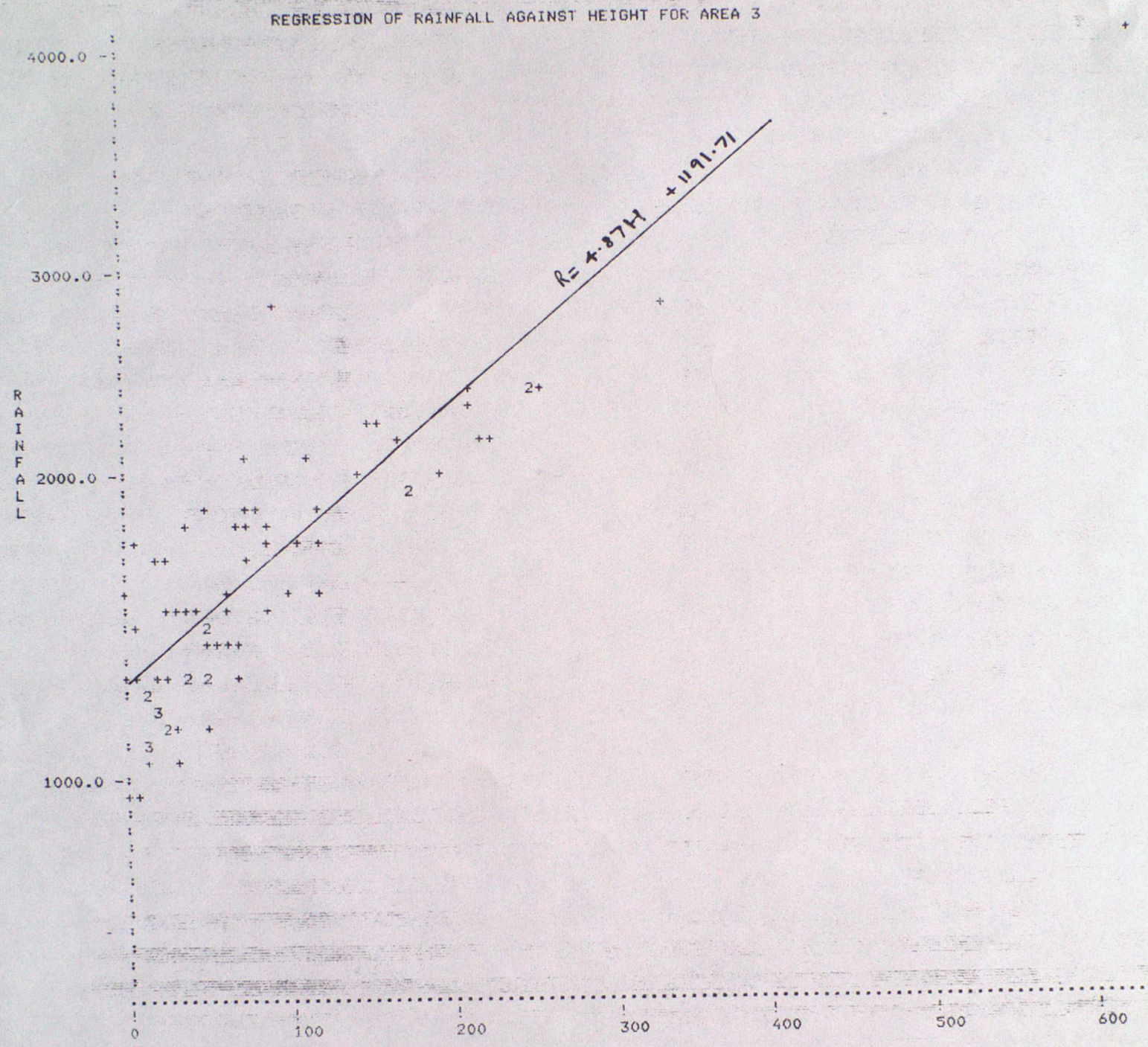

REGRESSION OF RAINFALL AGAINST HEIGHT FOR AREA 2
= 2.58 H + 938.35
RAINFALL (mm)
2000.0
1000.0
0
100
200
300
400
500

Fig. 3c.


REGRESSION OF RAINFALL AGAINST HEIGHT FOR AREA 3
R= 4·874 + 1191·71
RAINFALL
4000.0
3000.0
2000.0
1000.0
0
100
200
300
400
500
600